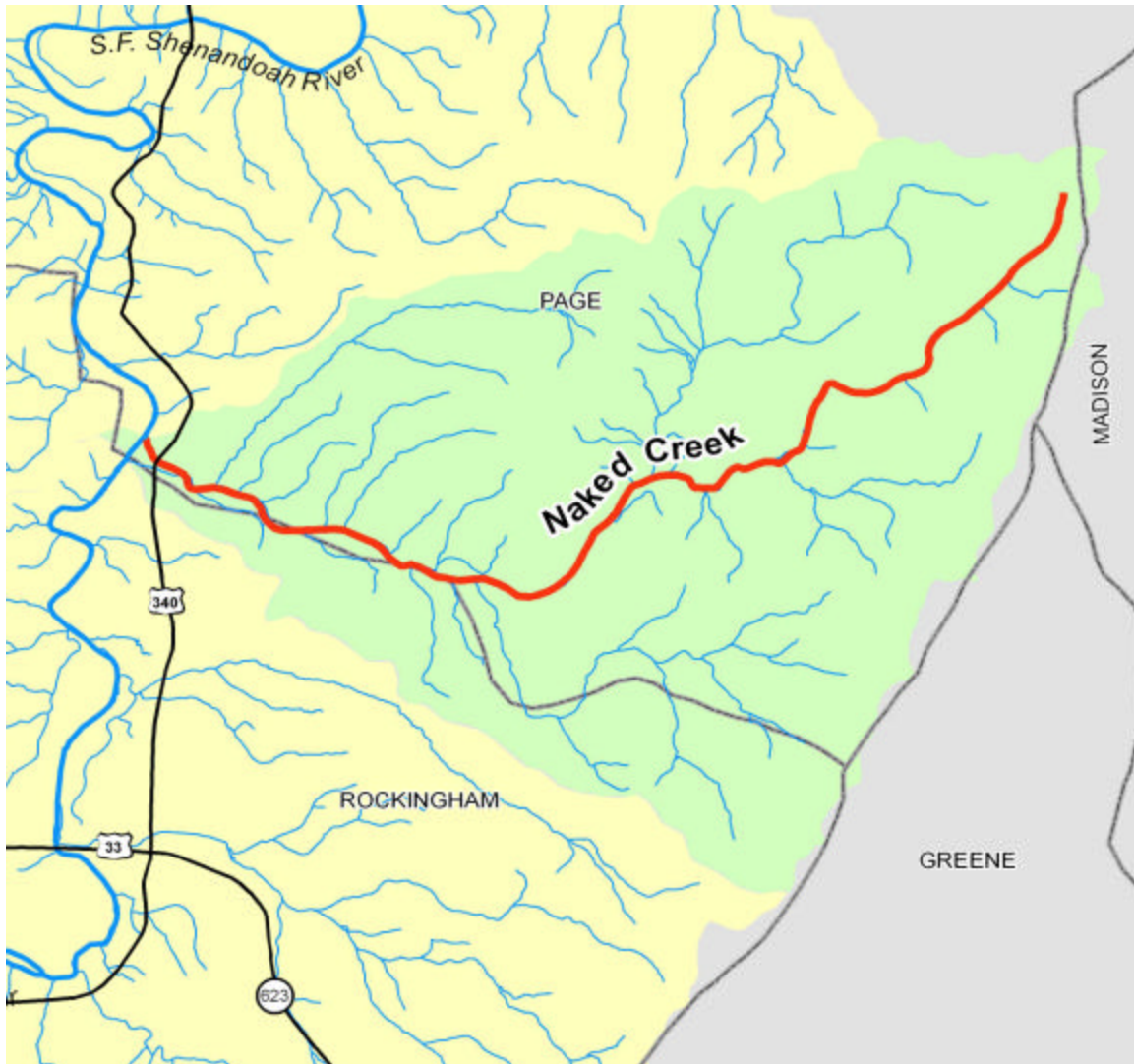


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# Stressor Analysis Report for Benthic Impairment in Naked Creek



**Submitted by:** Virginia Department of Environmental Quality

**Prepared by:** Engineering Concepts, Inc. and the Virginia Department of Environmental Quality

**Submitted:** May 2009

## Table of Contents

<b>LIST OF TABLES.....</b>	<b>III</b>
<b>LIST OF FIGURES.....</b>	<b>IV</b>
<b>PROJECT PERSONNEL .....</b>	<b>V</b>
<b>CHAPTER 1. INTRODUCTION.....</b>	<b>1-1</b>
1.1 Background.....	1-1
1.1.1 TMDL Definition and Regulatory Information .....	1-1
1.1.2 Impairment Listing .....	1-1
1.1.3 Watershed Location and Description .....	1-1
1.2 Designated Uses and Applicable Water Quality Standards.....	1-2
1.2.1 Designation of Uses (9 VAC 25-260-10).....	1-2
1.2.2 General Standard (9 VAC 25-260-20).....	1-2
<b>CHAPTER 2. WATERSHED CHARACTERIZATION .....</b>	<b>2-5</b>
2.1 Water Resources .....	2-5
2.2 Ecoregion .....	2-5
2.3 Soils and Geology .....	2-5
2.4 Climate .....	2-6
2.5 Land Use.....	2-6
2.6 Permitted Discharges.....	2-8
2.7 Biological Monitoring Data .....	2-8
2.8 Water Quality Data.....	2-13
<b>CHAPTER 3. BENTHIC STRESSOR ANALYSIS.....</b>	<b>3-22</b>
3.1 Introduction .....	3-22
3.2 Non-Stressors.....	3-22
3.2.1 pH.....	3-22
3.2.2 Temperature .....	3-23
3.2.3 Dissolved Oxygen and Biochemical Oxygen Demand .....	3-23
3.2.4 Nutrients .....	3-23
3.2.5 Ammonia.....	3-23
3.2.6 Water Column Toxics .....	3-24
3.2.7 Sediment.....	3-24
3.3 Possible Stressors.....	3-24
3.4 Most Probable Stressors .....	3-25
3.4.1 Habitat Instability .....	3-25
<b>CHAPTER 4. CONCLUSIONS.....</b>	<b>4-34</b>
<b>CHAPTER 5. PUBLIC PARTICIPATION.....</b>	<b>5-1</b>
<b>REFERENCES .....</b>	<b>1</b>

**List of Tables**

Table 2-1. Consolidation of NLCD Land Use Categories for Naked Creek Watershed.....	2-7
Table 2-2. Benthic Monitoring Stations in the Naked Creek Watershed. ....	2-9
Table 2-3. Benthic Assessment Scores for Station 1BNAK001.24 .....	2-10
Table 2-4. Benthic Assessment Scores for Station 1BNKW001.97. ....	2-11
Table 2-5. Benthic Assessment Scores for Station 1BNAK000.30. ....	2-12
Table 2-6. Habitat Scores for Station 1BNAK001.24. ....	2-13
Table 2-7. Habitat Scores for Station 1BNKW001.97. ....	2-13
Table 3-1. Stream Restoration and Stabalization Projects in Naked Creek from 2004 - 2008... 3-31	
Table 3-2. Stream Condition Index (SCI) Scores for Naked Creek Monitoring Stations in Fall 2008. ....	3-32

## List of Figures

Figure 1-1. Location of Naked Creek Watershed and Monitoring Stations.....	1-2
Figure 2-1. Land Use Distribution in Naked Creek Watershed.....	2-8
Figure 2-2. SCI Scores from Benthic Monitoring Stations 1BNAK001.24, 1BNKW001.97, and 1BNAK000.30. ....	2-9
Figure 2-3. Field pH Values at Water Quality Monitoring Station in Naked Creek.....	2-14
Figure 2-4. Dissolved Oxygen Values at Water Quality Monitoring Station in Naked Creek. ...	2-15
Figure 2-5. Temperature Values at Water Quality Monitoring Station in Naked Creek. ....	2-15
Figure 2-6. Total Solids Values at Water Quality Monitoring Station in Naked Creek. ....	2-16
Figure 2-7. Total Suspended Solids at Water Quality Monitoring Station in Naked Creek. ....	2-16
Figure 2-8. Biochemical Oxygen Demand (BOD <sub>5</sub> ) at Water Quality Monitoring Station in Naked Creek.....	2-17
Figure 2-9. COD Values at Water Quality Monitoring Station in Naked Creek. ....	2-17
Figure 2-10. Ammonia Values at Water Quality Monitoring Station in Naked Creek. ....	2-18
Figure 2-11. Nitrite Values at Water Quality Monitoring Station in Naked Creek. ....	2-18
Figure 2-12. Nitrate Values at Water Quality Monitoring Station in Naked Creek. ....	2-19
Figure 2-13. TKN Values at Water Quality Monitoring Station in Naked Creek. ....	2-19
Figure 2-14. Total Phosphorous Values at Water Quality Monitoring Station in Naked Creek....	2-20
Figure 2-15. Diurnal Dissolved Oxygen Results from Station 1BNAK001.24. ....	2-21
Figure 3-1. Topography of Naked Creek Watershed.....	3-26
Figure 3-2. Spring 2004 Aerial Imagery Showing Evidences of Disturbance and Channel Instability in Naked Creek Following Hurricane Isabel in 2003 (Aerial Imagery Location A).....	3-27
Figure 3-3. Aerial Imagery (Location F) Showing Migration of the Naked Creek Channel from 2004 to 2007. ....	3-28
Figure 3-4. Aerial Imagery (Location B) Showing Migration of the Naked Creek Channel from 2004 to 2007. ....	3-29
Figure 3-5. Aerial Imagery (Location E) and Ground-level Photography Showing Migration of the Naked Creek Channel and Formation of Bars from 2004 to 2007. ....	3-29
Figure 3-6. Aerial Imagery (Location D) Showing Migration of the Naked Creek Channel and Formation of Islands from 2004 to 2007.....	3-30
Figure 3-7. Aerial Imagery (Location C) Showing Migration of the Naked Creek Channel and Formation of Bars and Islands from 2004 to 2007. ....	3-31
Figure 3-8. Location of New Established Benthic Monitoring Station.....	3-33

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## Chapter 1. Introduction

### 1.1 Background

#### 1.1.1 TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that exceed state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL represents the total load of a pollutant that a water body can receive without exceeding state water quality standards. The TMDL process establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the allowable load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

#### 1.1.2 Impairment Listing

Naked Creek (VAV-B36R-01) was first listed as an impaired stream in 1998 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report indicating that the Aquatic Life Use (i.e., benthic criteria) was not being supported (VADEQ, 1998). The stream segment was further listed in 2002, 2004, 2006, and 2008 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report based on Virginia Department of Environmental Quality (VADEQ) monitoring data (VADEQ, 2002, 2004, 2006, and 2008).

The impaired portion of Naked Creek begins at the headwaters and continues downstream 12.44 miles to the confluence with the South Fork Shenandoah River. The impairment was listed for exceedances of the General Standard (Benthic) for not supporting Aquatic Life Use due to a moderately impaired benthic rating during the 1998 assessment at station 1-BNAK001.24 located at Route 603. During the 2002 assessment period, this station exhibited a slight impairment and was assessed as partially supporting the Aquatic Life Use. The station was not assessed during the 2004 assessment cycle (VADEQ, 2004). During the 2006, 2008, and 2010 assessments, Naked Creek was listed as impaired due to VaSCI scores below 60.

#### 1.1.3 Watershed Location and Description

The Naked Creek watershed is located predominately in Page (82.4%) and Rockingham (16.7%) Counties, Virginia (Figure 1-1). A small portion (0.9%) of the watershed lies within Madison and Greene Counties, Virginia. Naked Creek begins at its headwaters near Tanners Ridge on Route 682 and flows southwest approximately 12.5 miles to the confluence with South Fork Shenandoah River at Verbena, Virginia. The Naked Creek watershed is approximately 28,150 acres, with forest constituting approximately 84% of this area. The remaining land uses are divided between pasture (10%), residential (5%), and cropland (1%). A summary of the land use distribution is listed in Table 2-1.

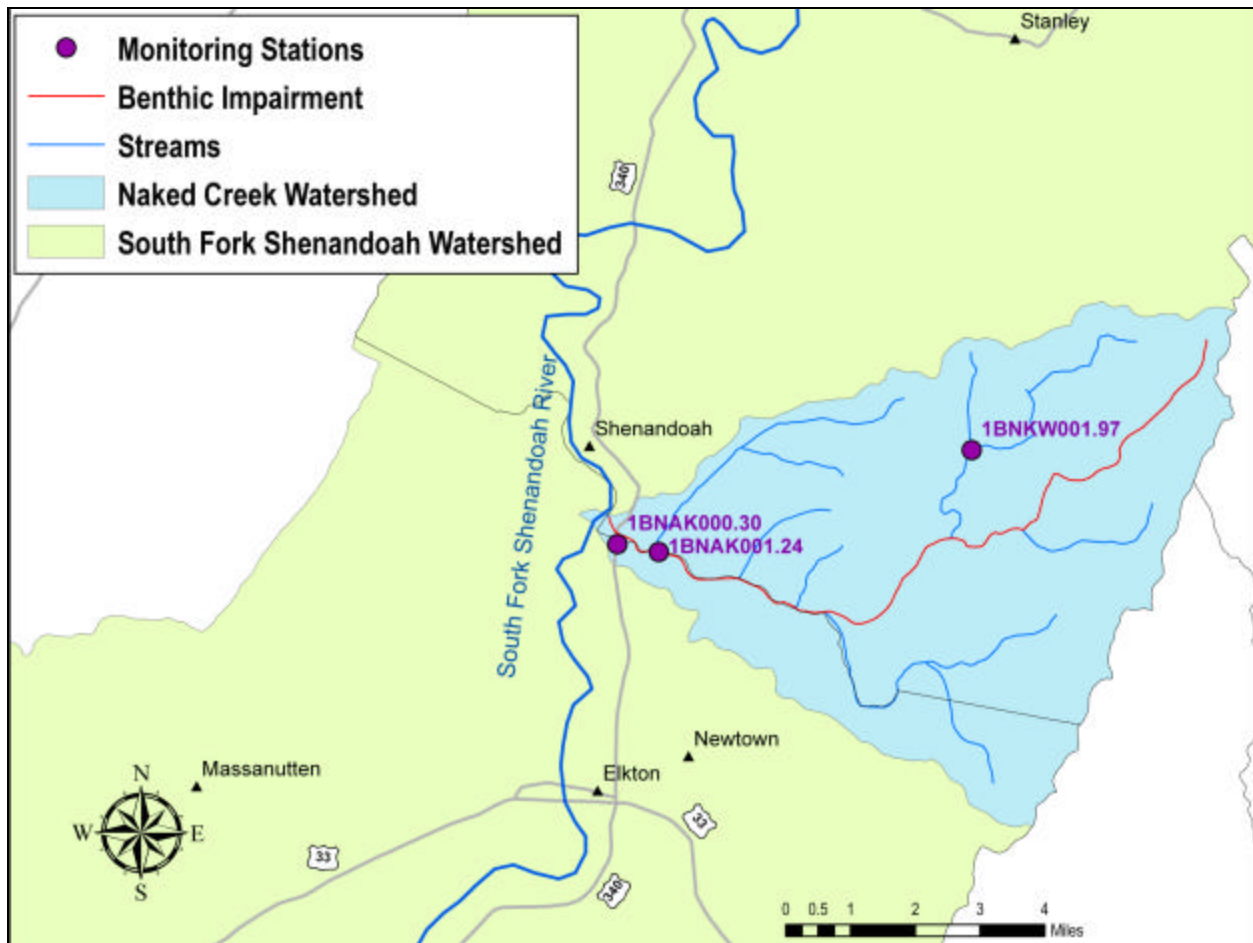


Figure 1-1. Location of Naked Creek Watershed and Monitoring Stations.

## 1.2 Designated Uses and Applicable Water Quality Standards

### 1.2.1 Designation of Uses (9 VAC 25-260-10)

“A. All state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish).” (SWCB, 2002)

### 1.2.2 General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia is stated as follows:

“A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which



contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.

Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled.” (SWCB, 2002)

The VADEQ conducts the biological monitoring program in Virginia to evaluate compliance with the General standard. Evaluations of monitoring data to determine whether or not a stream segment has a benthic impairment focus on benthic macroinvertebrates (i.e., bottom-dwelling; visible to eyes; insects, mollusks, crustaceans, and annelid worms). Changes in water quality generally result in alterations to the quantity and diversity of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring has been conducted by VADEQ since the early 1970's.

From 1990 to 2006, the U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocol II (RBP II) was the official protocol used to assess compliance with the general standard in Virginia (Barbour et al., 1999). The RBP II was employed beginning in the fall of 1990 to utilize standardized and repeatable assessment methodology. For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, benthic samples are typically collected and analyzed twice a year in the spring and in the fall. The RBP II procedure evaluates the benthic macroinvertebrate community by comparing ambient monitoring "network" stations to "reference" sites. Reference bio-monitoring stations have been identified by regional biologists that are both representative of regional physiographic and ecological conditions and have a healthy, non-impaired benthic community. The RBP II evaluation also accounts for the natural variation noted in streams in different ecoregions. One additional product of the RBP II evaluation is a habitat assessment. This is a stand alone assessment that describes bank condition and other stream and riparian corridor characteristics and serves as a measure of habitat suitability for the benthic community. Determination of the degree of support for the aquatic life designated use is based on biological monitoring data and the best professional judgment of the regional biologist, relying primarily on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of "moderately impaired" or "severely impaired" is placed on the state's 303(d) list of impaired streams (DEQ, 2002).

Beginning with the 2008 Assessment, VADEQ upgraded its bio-monitoring and biological assessment methods to use the Virginia Stream Condition Index (VaSCI) for Virginia's non-coastal areas (Tetra Tech, 2002). Rather than being based on a paired reference site approach



(like the RBPII method), the VaSCI is based on a regional condition. This multi-metric index is based on eight bio-monitoring metrics, with a scoring range of 0-100, that include some different metrics than those used in the RBP II, but are based on the same taxa inventory. A maximum score of 100 represents the best benthic community sites. The threshold criterion defines “non-impaired” sites as those with a VaSCI of 60 or above, and “impaired” sites as those with a score below 60 (VADEQ, 2006).

## **Chapter 2. Watershed Characterization**

### **2.1 Water Resources**

Naked Creek begins at its headwaters near Tanners Ridge on Route 682 and flows southwest approximately 12.5 miles to the confluence with the South Fork Shenandoah River at Verbenia, Virginia. The South Fork Shenandoah River joins the North Fork Shenandoah River to form the Shenandoah River. The Shenandoah River flows into the Potomac River, which eventually discharges into the Chesapeake Bay.

### **2.2 Ecoregion**

The Naked Creek watershed is divided into two ecoregions. The eastern portion of the watershed lies within the Blue Ridge Mountains ecoregion and the western portion lies within the Central Appalachian Ridges and Valleys ecoregion.

The Blue Ridge Mountains vary from narrow ridges to hilly plateaus to more massive mountainous areas. The mostly forested slopes, high-gradient, cool, clear streams, and rugged terrain occur primarily on metamorphic rocks, with minor areas of igneous and sedimentary geology. Appalachian Oak Forests and northern hardwoods coupled with shrub, grass, heath balds, hemlock, cove hardwoods, and oak-pine communities illustrate the floristic diversity of this ecoregion (USEPA, 2002).

The Central Appalachians is primarily a high, dissected, rugged plateau which is composed of sandstone, shale, conglomerate and coal. The land cover is mostly forested due to rugged terrain, cool climate and infertile soils which limit agriculture. A mixed mesophytic forest with areas of Appalachian oak and northern hardwood forest cover the high hills and low mountains. The agricultural lands of the ecoregion are located in the valleys, where the main agricultural activities include livestock and dairy farming and Christmas trees growing on plantations.

### **2.3 Soils and Geology**

The soils found in the Naked Creek watershed are primarily in the Catocin, Dekalb, Fauquier, Myersville, Sylco, Sylvatus, and Thurmont series. The components are on hillslopes on mountain slopes, mountain slopes on mountains, mountains on uplands, and mountainsides on mountains. The parent material consists of residuum weathered from phyllite, slate, siltstone, shale, sandstone, quartzite, and greenstone. Depth to a root restrictive layer is 20 to 60 inches and to bedrock (lithic) is 10 to 84 inches. The natural drainage class is well drained to excessively drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is low to moderate. Shrink-swell potential is low. These soils are not flooded or ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon varies between one and three percent. Non-irrigated land capability classifications are 3e, 6e, 7e, and 7s. The soils do not meet hydric criteria.

## **2.4 Climate**

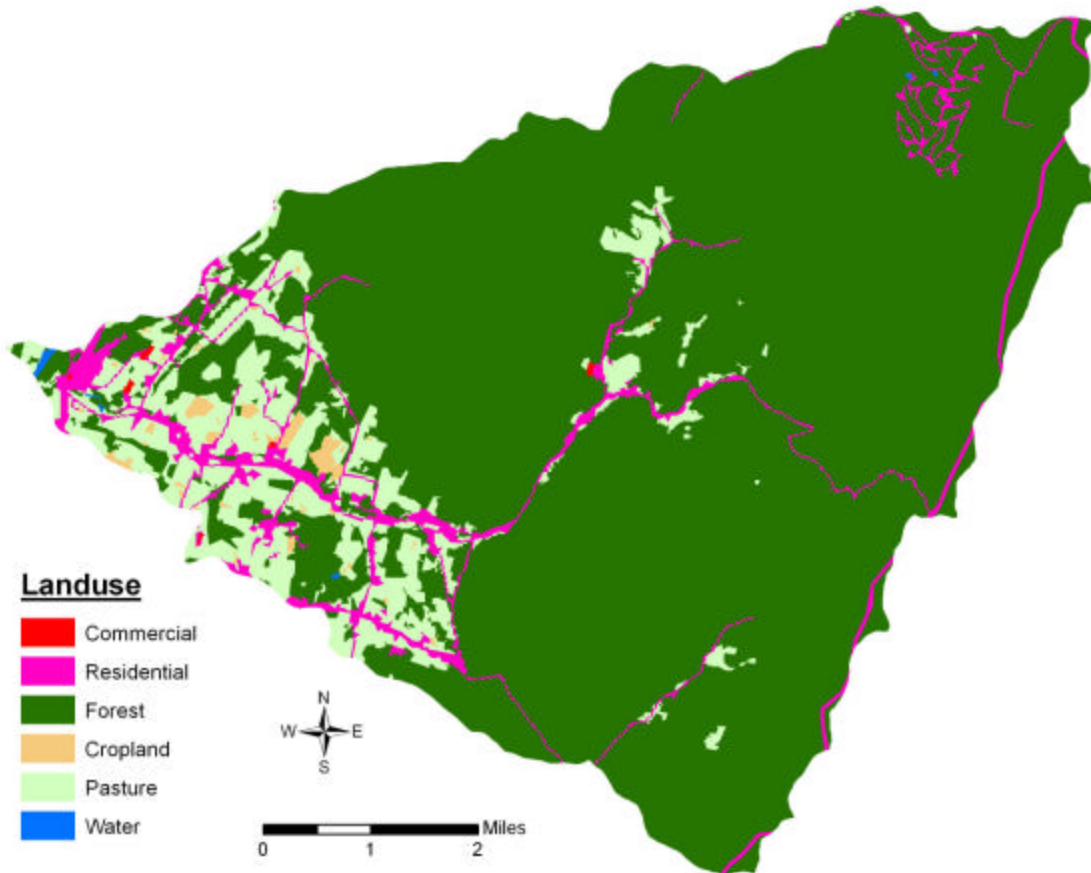
The climate of the Naked Creek watershed is characterized based on the meteorological observations from 03/01/1941 to 12/31/2007 assembled by the Southeast Regional Climate Center for the Luray, Virginia (5E8) station. Average annual precipitation is 40.19 inches with 56.5% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2008). Average annual snowfall is 23.2 inches with the highest snowfall occurring during January (SERCC, 2008). Average annual daily temperature is 67.7°F. The highest average daily temperature of 86.5°F occurs in July, while the lowest average daily temperature of 21.2°F occurs in January (SERCC, 2008).

## **2.5 Land Use**

The National Land Cover Data (NLCD) produced by U.S. Geological Survey (USGS) in cooperation with the USEPA was used for this study. NLCD was developed from 30-meter Landsat 7 thematic mapper (TM) data between 1990 and 1994 and updated with data between 1999 and 2003 acquired by the Multi-resolution Land Characterization (MRLC) Consortium, a partnership between United States Geological Survey (USGS), USEPA, U.S. Forest Service, National Oceanic and Atmospheric Administration (NOAA), Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), National Park Service (NPS), National Aeronautics and Space Administration (NASA), and United States Fish and Wildlife Service (USFWS). NLCD is classified into 21 land use types. The NLCD land use types within the watershed were consolidated into six categories based on similarities in hydrologic and pollutant production features (Table 2-1). Land use distribution in the Naked Creek watershed is presented in Figure 2-1.

**Table 2-1. Consolidation of NLCD Land Use Categories for Naked Creek Watershed.**

<b>NLCD Land Use Classification (Class No.)</b>	<b>TMDL Land Use Categories</b>	<b>Area (ac)</b>	<b>Portion of Total (%)</b>
Cultivated Crops (82)	Cropland	176.2	0.6
Pasture/Hay (81)	Pasture	2,827.3	10.0
Developed, Open Space (21) Developed, Low Intensity (22)	Residential	1,344.0	4.8
Developed, Medium Intensity (23) Developed, High Intensity (24)	Commercial	20.0	0.1
Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43) Woody Wetlands (91) Emergent Herbaceous Wetlands (92) Barren Land, Rock, Sand, Clay (31)	Forest	23,758.8	84.4
Open Water (11)	Water	20.5	0.1
<b>TOTAL</b>		<b>28,146.8</b>	<b>100.0</b>



**Figure 2-1. Land Use Distribution in Naked Creek Watershed.**

## 2.6 Permitted Discharges

Permitted point sources in the Naked Creek watershed include two general permits issued for domestic sewage discharges of less than or equal to 1,000 gallons per day, two mining stormwater permits, and one petroleum stormwater permit.

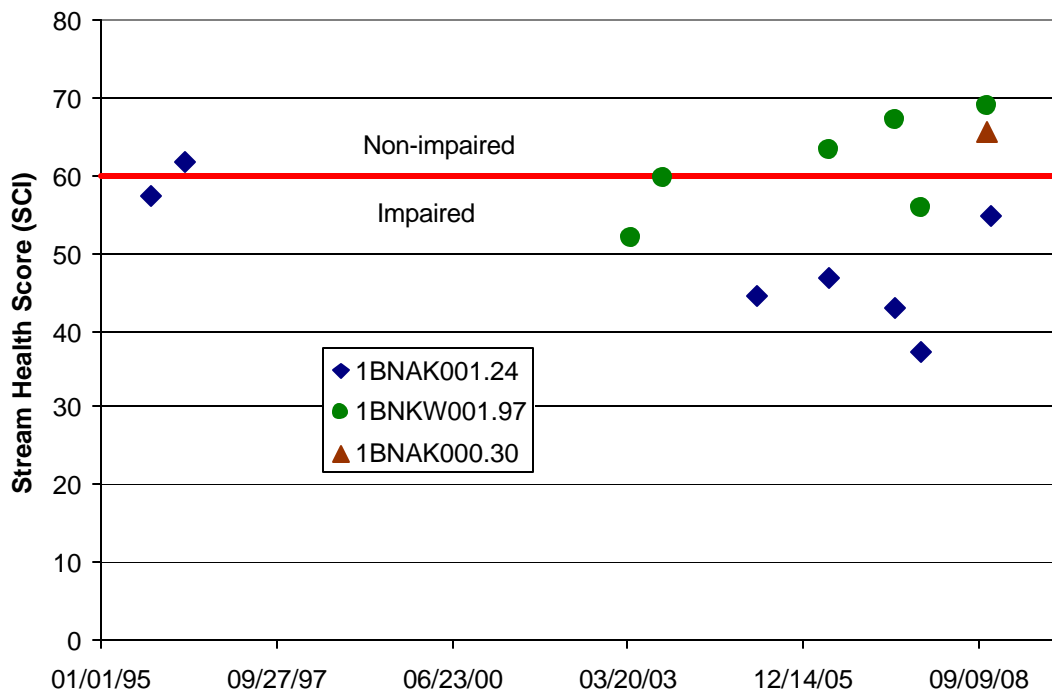
## 2.7 Biological Monitoring Data

Benthic monitoring data were available at three monitoring stations within the Naked Creek watershed (Figure 1-1 and Table 2-2). Figure 2-2 shows the SCI scores at each location. At the primary Naked Creek monitoring site, 1BNAK001.24, benthic conditions have been impaired during 6 of the 7 monitoring events and have averaged an SCI score of 49.32. Further upstream on West Brach Naked Creek, station 1BNKW001.97, only 2 out of 6 monitoring events have shown impaired conditions, and SCI scores have averaged 61.18 (unimpaired). Station 1BNAK000.30 was recently added in Fall 2008 to assess conditions closer to the mouth and away from a naturally disturbed area (see Section 3.4.1). Monitoring at this station showed no impairment and improved conditions compared to 1BNAK001.24, which is just a mile upstream.

The benthic scores included in Figure 2-2 are described in greater detail in Table 2-3, Table 2-4, and Table 2-5. In general, the lowest SCI metrics at impaired sites were the %Scraper scores and the percent Plecoptera and Trichoptera – Hydropsychidae (%PT-H) scores. Impaired benthic samples were often dominated by Hydropsychidae, the net-spinning caddisflies.

**Table 2-2. Benthic Monitoring Stations in the Naked Creek Watershed.**

Stream Name	Monitoring Station	Station Location
Naked Creek	1BNAK001.24	Route 603
Naked Creek	1BNAK000.30	Route 340
West Branch Naked Creek	1BNKW001.97	Below confluence of unnamed tributary



**Figure 2-2. SCI Scores from Benthic Monitoring Stations 1BNAK001.24, 1BNKW001.97, and 1BNAK000.30.**

**Table 2-3. Benthic Assessment Scores for Station 1BNAK001.24**

	10/12/95	04/22/96	03/28/05	05/11/06	05/17/07	10/18/07	11/14/08
Richness Score	95.45	59.09	36.36	72.73	63.64	36.36	68.18
EPT Score	72.73	81.82	45.45	81.82	45.45	36.36	63.64
%Ephem Score	27.19	74.91	81.57	41.14	33.46	29.13	48.16
%PT-H Score	12.77	28.66	0.00	4.89	0.00	5.02	8.03
%Scraper Score	26.43	25.71	1.73	8.43	6.21	8.65	29.53
%Chironomidae Score	98.48	71.43	92.86	46.96	81.41	99.11	98.10
%2Dom Score	52.55	69.31	24.51	49.01	47.24	16.77	46.79
%MFB Index Score	72.86	82.08	74.32	70.20	65.80	66.31	75.07
SCI Score	57.31	61.63	44.60	46.90	42.90	37.21	54.69
SCI Assessment	Impaired	Non-impaired	Impaired	Impaired	Impaired	Impaired	Impaired
RBPII Score	60.87	54.17	42.9				
RBPII Assessment	Slight	Slight	Moderate				



**Table 2-4. Benthic Assessment Scores for Station 1BNKW001.97.**

	04/08/03	10/15/03	05/11/06	05/23/07	10/18/07	10/28/08
Richness Score	50.00	81.82	72.73	77.27	59.09	68.18
EPT Score	63.64	100.00	100.00	100.00	72.73	81.82
%Ephem Score	14.95	22.84	55.28	34.27	32.32	50.72
%PT-H Score	72.57	61.80	53.39	75.54	29.15	54.29
%Scraper Score	6.46	9.69	1.60	6.51	38.39	48.86
%Chironomidae Score	82.50	65.00	72.73	87.39	94.34	95.80
%2Dom Score	48.17	56.36	71.66	75.29	46.35	66.79
%MFB Index Score	77.33	80.29	78.76	81.70	74.37	85.76
SCI Score	51.95	59.72	63.27	67.25	55.84	69.03
SCI Assessment	Impaired	Impaired	Non-impaired	Non-impaired	Impaired	Non-impaired
RBPII Score	54.5	60.9				
RBPII Assessment	Slight	Slight				

**Table 2-5. Benthic Assessment Scores for Station 1BNAK000.30.**

	10/28/08
Richness Score	63.64
EPT Score	54.55
%Ephem Score	80.16
%PT-H Score	2.42
%Scraper Score	68.50
%Chironomidae Score	98.28
%2Dom Score	72.25
%MFBI Score	84.81
SCI Score	65.58
SCI Assessment	Non-impaired
RBPII Score	
RBPII Assessment	

Habitat data associated with each biological assessment were obtained and are summarized in Table 2-6 and Table 2-7. Individual metric scores of 10 or below are considered poor or marginal. These scores are highlighted for easy identification. Habitat scores are poor or marginal at station 1-BNAK001.24 for channel alteration and riparian vegetation with the other metrics scoring generally well. These assessments were generally verified by field reconnaissance, though less suitable bank stability conditions on the main stem upstream of station 1-BNAK001.24 were observed. In one particular segment, a vertical cut bank about 15' tall likely contributing significant sediment load during storm events was observed. State Route 609 is located immediately adjacent to the main stem of Naked Creek for most of its length, which is likely contributing to the channel alteration and lack of riparian vegetation noted in the habitat scores. Habitat data collected at station 1-BNKW001.97 indicate generally favorable conditions in all metrics with one poor or marginal score in five metrics. Three of those poor or marginal scores were noted in the sample collected in the fall of 2007.

**Table 2-6. Habitat Scores for Station 1BNAK001.24.**

Habitat Metrics	SAMPLING DATES					
	10/12/1995	4/22/1996	3/28/2005	5/11/2006	5/17/2007	10/18/2007
Channel Alteration	10	18	10	10	9	11
Bank Stability	14	14	14	15	15	18
Bank Vegetation	14	14	14	12	18	17
Cover	12	14				
Embeddedness	14	16	18	13	14	15
Channel Flow Status	16	18	19	17	14	13
Graze	20	18				
Riffle Stability	14	18	16	15	16	16
Riparian Vegetation	10	10	9	9	9	11
Sediment Disposition	12	16	14	15	14	14
Substrate	16	16	19	18	17	18
Velocity	16	16	19	17	16	16
<b>Total Habitat Score</b>	<b>168</b>	<b>188</b>	<b>152</b>	<b>141</b>	<b>142</b>	<b>149</b>

**Table 2-7. Habitat Scores for Station 1BNKW001.97.**

Habitat Metrics	SAMPLING DATES				
	4/8/2003	10/15/2003	5/11/2006	5/23/2007	10/18/2007
Channel Alteration	19	14	18	18	13
Bank Stability	15	7	17	17	16
Bank Vegetation	20	20	19	18	10
Cover					
Embeddedness	17	19	16	19	13
Channel Flow Status	20	19	14	15	7
Graze					
Riffle Stability	19	19	19	19	16
Riparian Vegetation	19	17	17	14	10
Sediment Disposition	20	16	19	17	15
Substrate	19	16	19	18	17
Velocity	10	16	14	14	11
<b>Total Habitat Score</b>	<b>178</b>	<b>163</b>	<b>172</b>	<b>169</b>	<b>128</b>

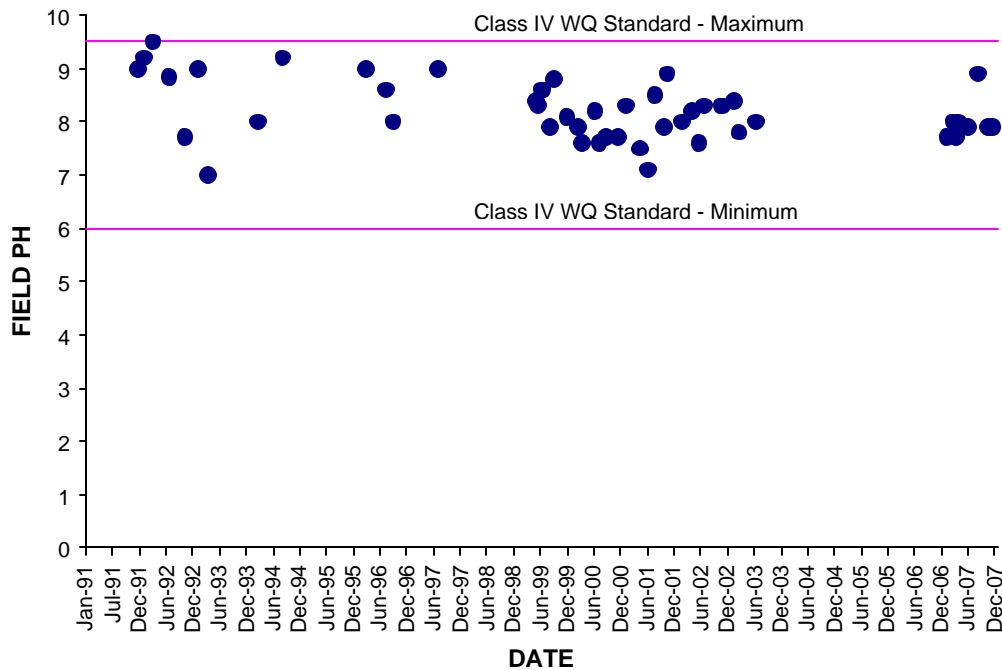
## 2.8 Water Quality Data

Ambient water quality data were collected at the primary benthic monitoring station, 1BNAK001.24, since 1991. These data are included in Figures 2.3 through 2.14. Where available; water quality standard, stressor screening criteria, minimum, or maximum values are shown for reference on the figures.

Generally, most of the data appear to be within the expected ranges for each parameter.

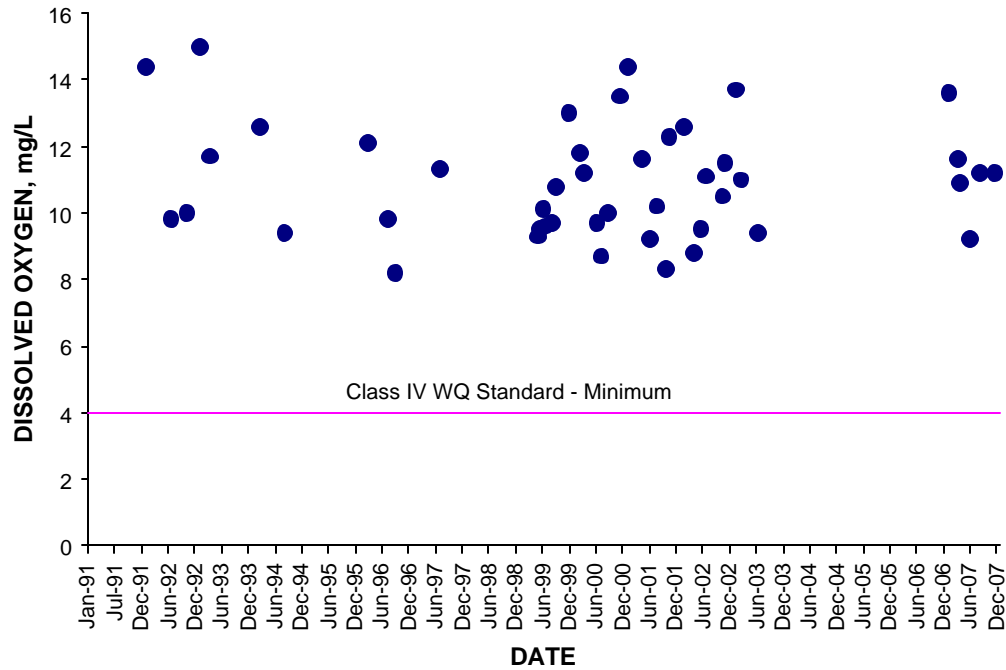
- All measured values for pH, DO, temperature, BOD, and COD are within expected ranges and do not appear to be stressors to the benthic community.
- No total phosphorus concentrations exceeded VADEQ's "threatened waters" threshold for total phosphorus (TP).
- No organic nitrogen values were above the stressor screening value with only two TKN values exceeding 0.1 mg/l.

- Average value of nitrate samples was 0.38 mg/l. Only one nitrate value (i.e., 1.81 mg/l) was above the stressor screening value. The maximum value recorded from the remaining samples was 1.08 mg/l.
- Nitrite values were not elevated with a maximum nitrate value of 0.05 mg/l.
- Ammonia values at all stations were not elevated, with all values at 0.04 mg/l.
- One TSS value (i.e., 16 mg/l) exceeded the stressor screening value of 10 mg/l and all remaining values were at or below 4 mg/l.
- All total solids concentrations were below the stressor screening value of 300 mg/l with values less than or equal to 100 mg/l.

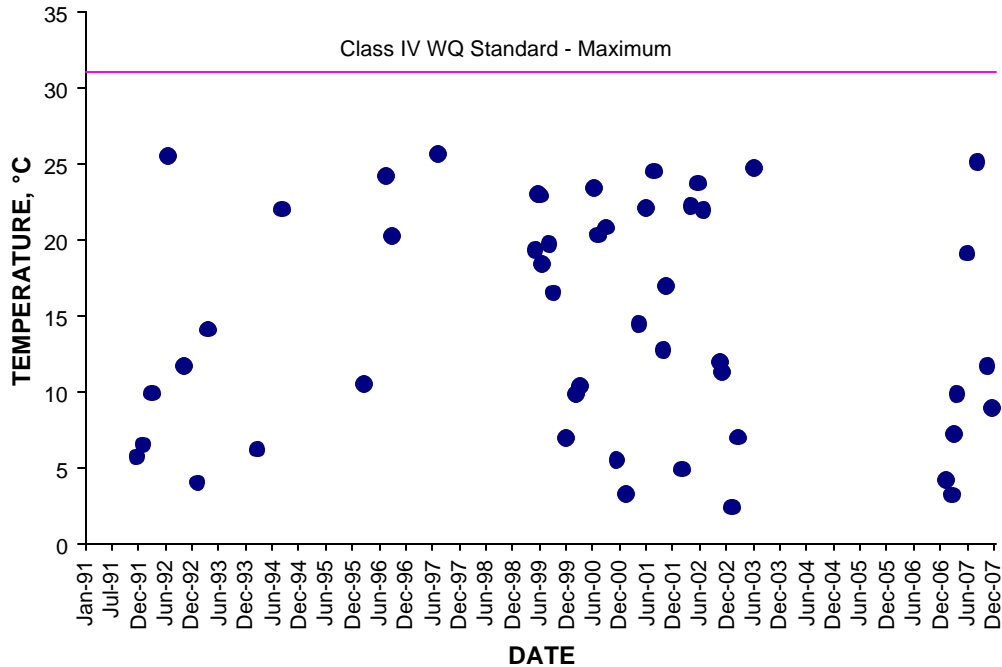


**Figure 2-3. Field pH Values at Water Quality Monitoring Station in Naked Creek.**

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**Figure 2-4. Dissolved Oxygen Values at Water Quality Monitoring Station in Naked Creek.**



**Figure 2-5. Temperature Values at Water Quality Monitoring Station in Naked Creek.**

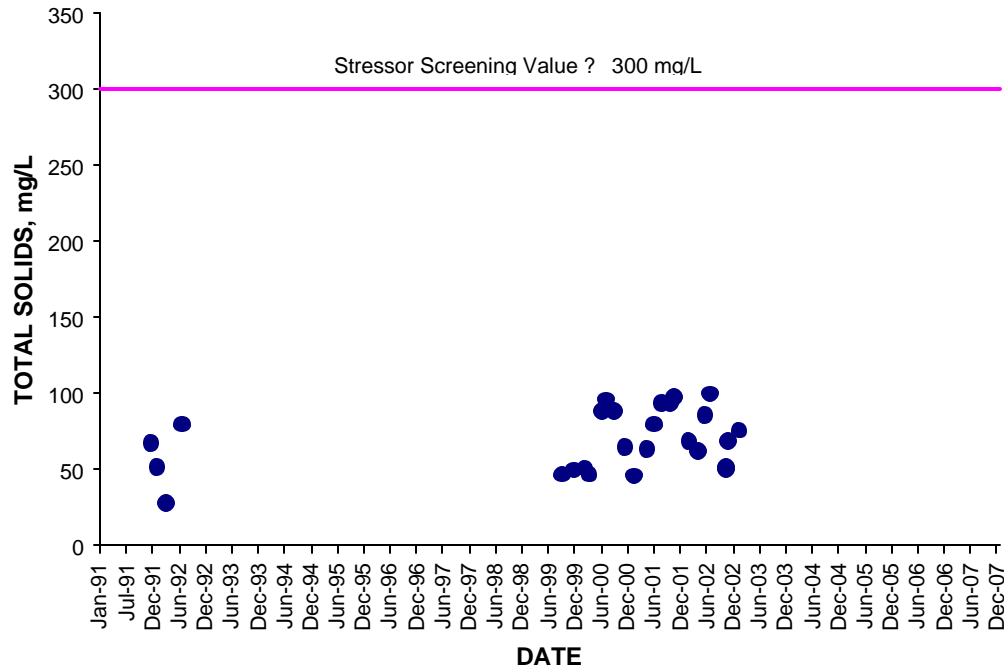


Figure 2-6. Total Solids Values at Water Quality Monitoring Station in Naked Creek.

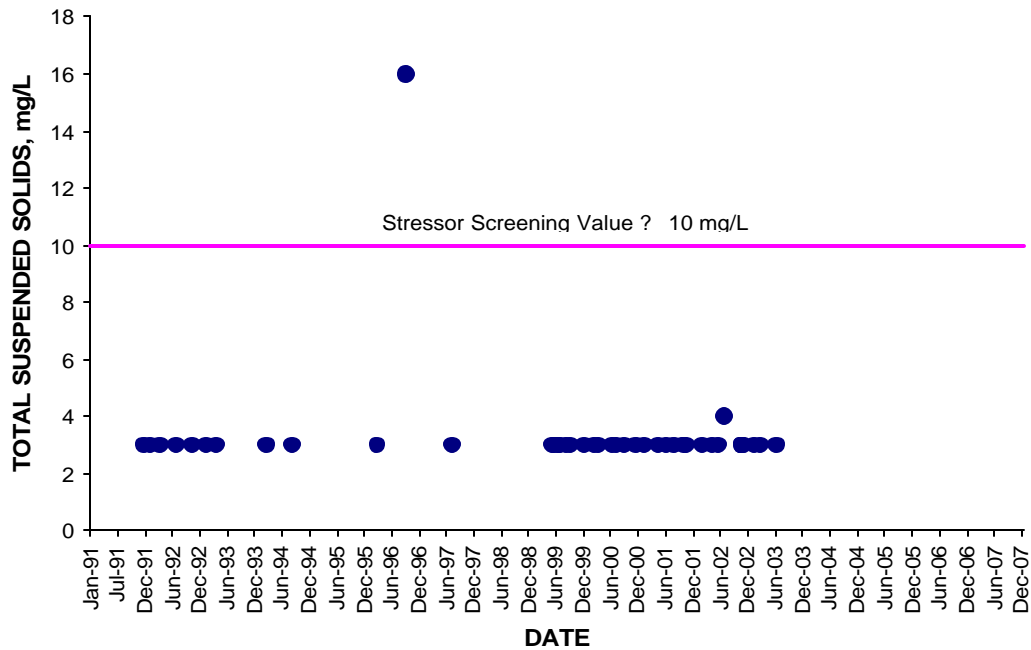


Figure 2-7. Total Suspended Solids at Water Quality Monitoring Station in Naked Creek.





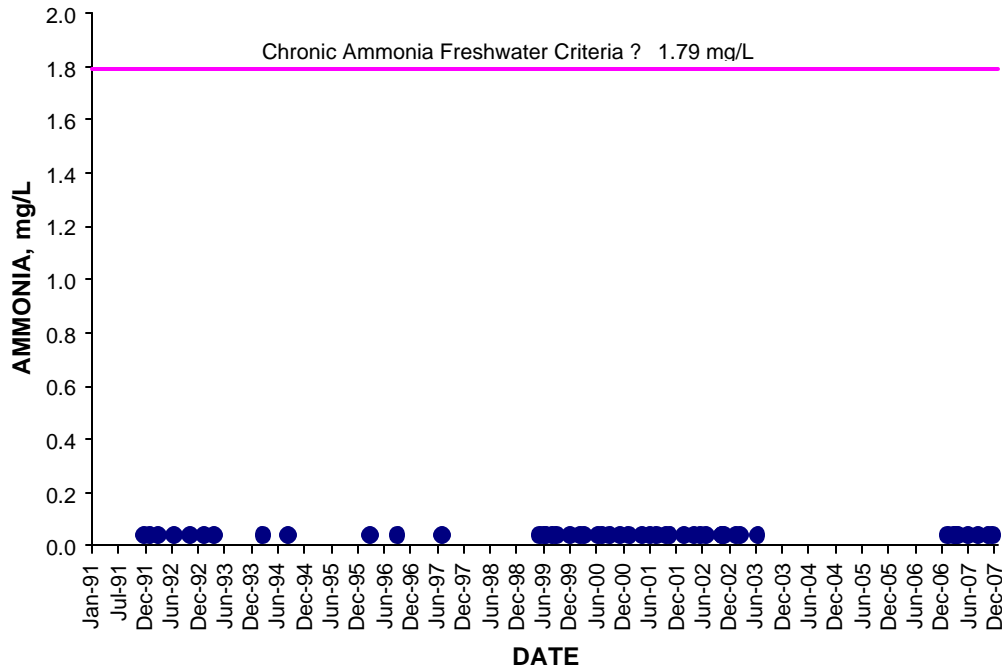


Figure 2-10. Ammonia Values at Water Quality Monitoring Station in Naked Creek.

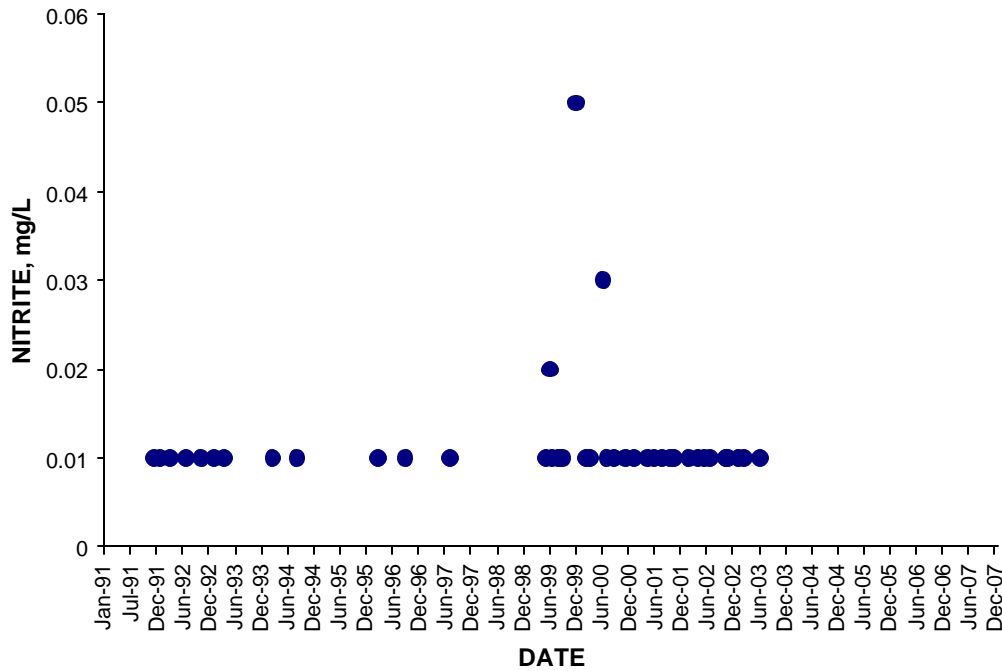


Figure 2-11. Nitrite Values at Water Quality Monitoring Station in Naked Creek.

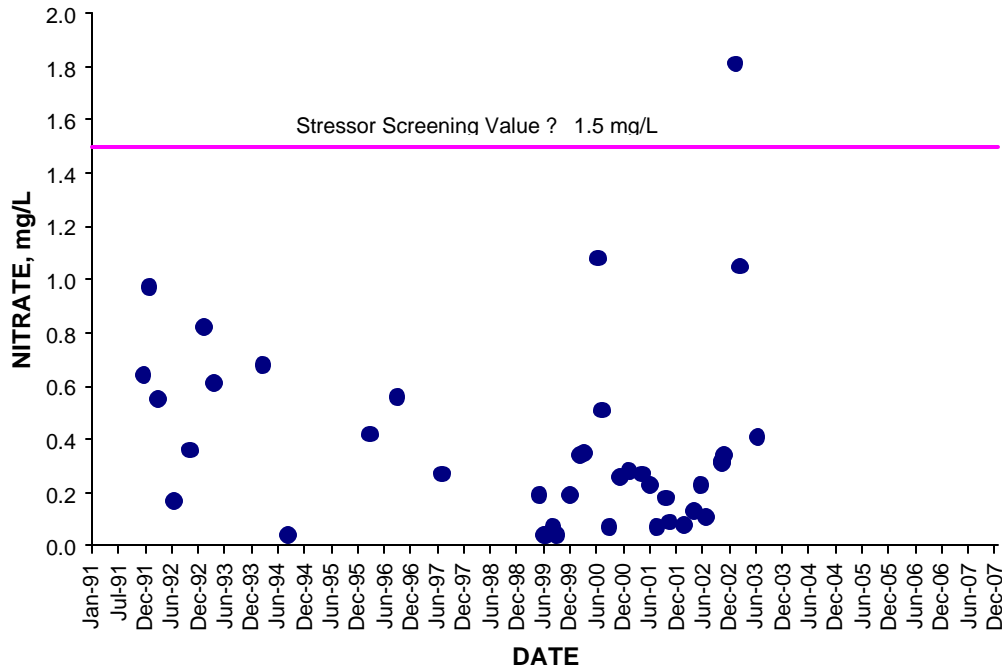


Figure 2-12. Nitrate Values at Water Quality Monitoring Station in Naked Creek.

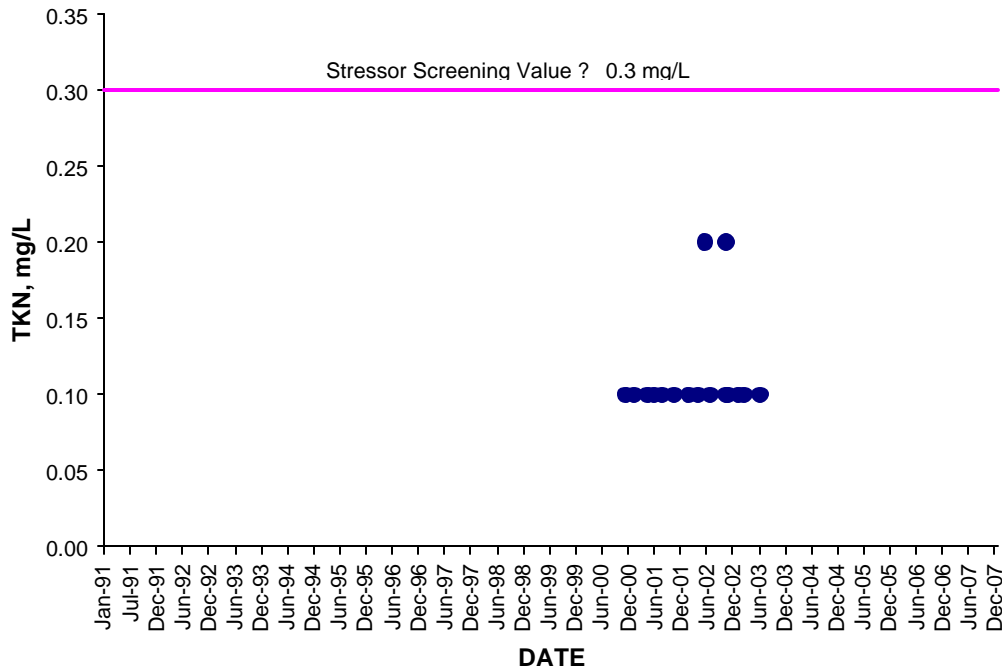
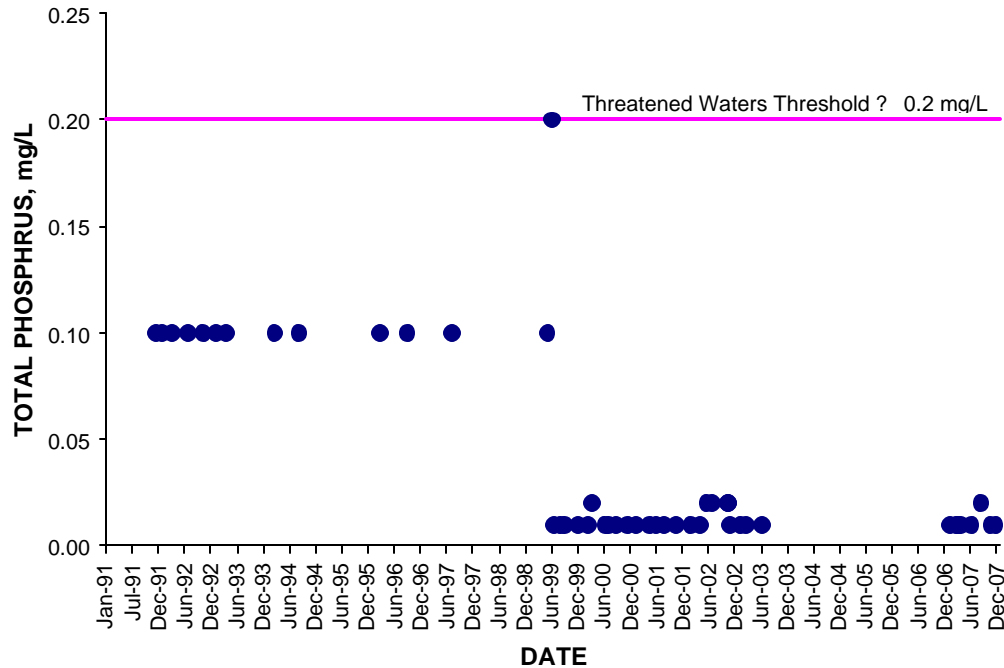
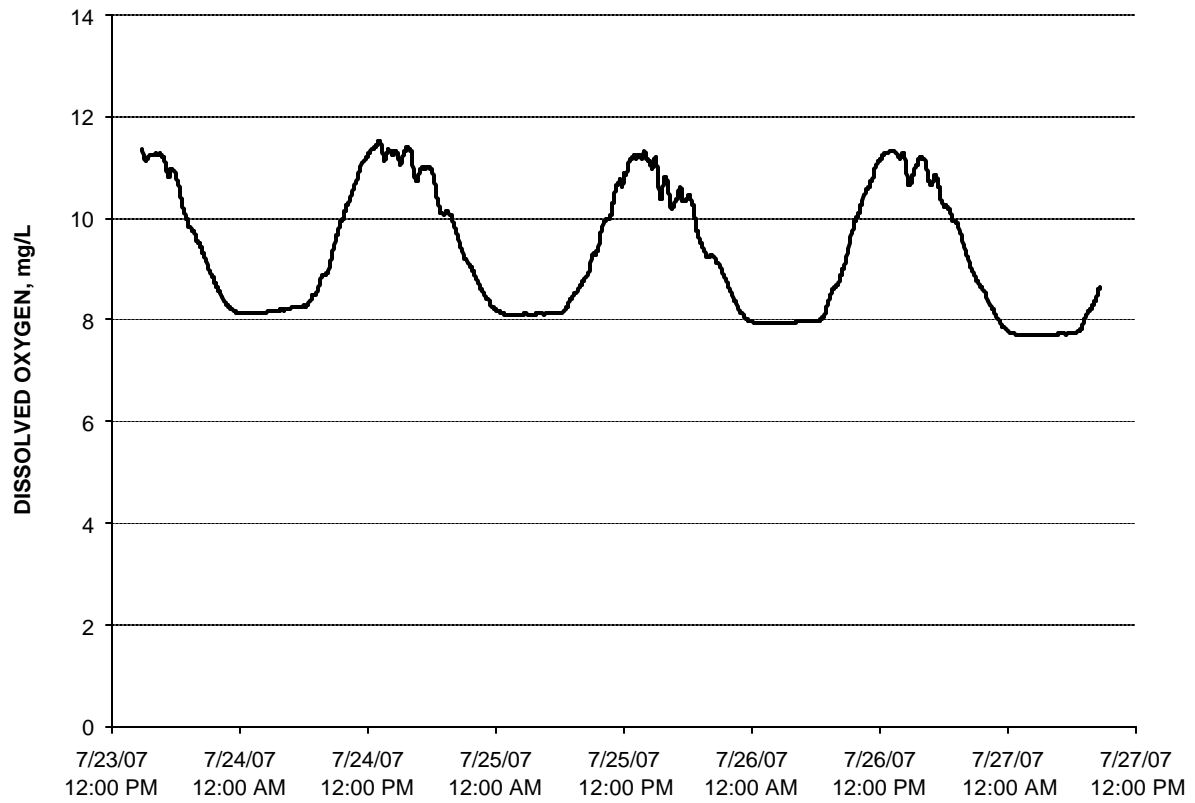


Figure 2-13. TKN Values at Water Quality Monitoring Station in Naked Creek.



**Figure 2-14. Total Phosphorous Values at Water Quality Monitoring Station in Naked Creek.**

Diurnal dissolved oxygen testing was completed at one location on Naked Creek in July 2007. Figure 2.15 shows data collected over a five-day period in July 2007 in Naked Creek at station 1-BNAK001.24. Dissolved oxygen values varied from 7.69 mg/l to 11.51 mg/l for the five-day period. This indicates that low dissolved oxygen concentration is not a stressor, and supports the conclusion that nutrients are not a stressor as well.



**Figure 2-15. Diurnal Dissolved Oxygen Results from Station 1BNAK001.24.**

## Chapter 3. Benthic Stressor Analysis

### 3.1 Introduction

TMDLs must be developed for a specific pollutant. Since the benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Naked Creek. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from VADEQ monitoring provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible.

Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause.

The evaluation includes possible stressors such as dissolved oxygen, temperature, pH, metals, organic chemicals, nutrients, toxic compounds, and sediments. Each candidate stressor was evaluated based on available monitoring data, field observations, and consideration of potential sources in the watershed. Depending on the weight of evidence available, each potential stressor was placed into one of the following three categories:

Non-stressor: Stressor with data indicating normal conditions, without water quality standard exceedances, or without observable impacts usually associated with the stressor.

Possible stressor: Stressor with data indicating possible links to the benthic impairment, but without conclusive data to demonstrate direct impact on benthic community.

Most probable stressor(s): Stressor with conclusive data linking it to the poor health of the benthic community, or the most plausible of the possible stressors. TMDL developed for the most probable stressor(s).

### 3.2 Non-Stressors

#### 3.2.1 pH

Benthic macroinvertebrates require a specific pH range of 6.0 to 9.0 to thrive. Changes in pH may adversely affect the survival of benthic macroinvertebrates. Treated wastewater, mining discharge, and urban runoff can potentially alter in-stream levels of pH. No exceedance of the minimum or maximum pH standard was reported at VADEQ station 1-BNAK001.24 on the impaired segment. Therefore, pH does not appear to be adversely impacting benthic communities in Naked Creek and is classified as a non-stressor.

### **3.2.2 Temperature**

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Naked Creek is classified as a Class IV mountain stream with a maximum temperature standard of 31°C. No exceedances of the temperature standard were recorded by VADEQ ambient monitoring, or by monitoring during collection of the biological samples. Therefore, no evidence supported temperature as a stressor, and it was classified as a non-stressor.

### **3.2.3 Dissolved Oxygen and Biochemical Oxygen Demand**

Adequate dissolved oxygen (DO) levels are necessary for invertebrates and other aquatic organisms to survive in the benthic sediments of rivers or streams. Decreases in in-stream oxygen levels can result in oxygen depletion or anoxic sediments, which adversely impact the river's benthic community. All field DO samples, including diurnal monitoring complied with the DO criteria (i.e., 5.0 mg/l); therefore, dissolved oxygen is not considered to be impacting the benthic community and was classified as a non-stressor.

Elevated biochemical oxygen demand (BOD) levels can contribute to low DO levels, adversely affecting the benthic community. The majority of BOD samples collected were 2.0 mg/l or below except for two samples with values at 3.0 mg/l. Since observed BOD values were not elevated, aside from two values, BOD was classified as a non-stressor.

### **3.2.4 Nutrients**

Excessive nutrient inputs can lead to excessive algal growth, eutrophication, and low DO concentrations that may adversely affect the survival of benthic macroinvertebrates. In particular, DO levels may become low during overnight hours due to respiration. All nutrient constituents were consistently low in Naked Creek. No samples exceeded VADEQ's "threatened waters" threshold for total phosphorus (TP). No organic nitrogen values were above the stressor screening value with only two TKN values exceeding 0.1 mg/l. Only one nitrate value was above the stressor screening threshold. Nitrite values were not elevated with a maximum nitrate value of 0.05 mg/l. Ammonia values were not elevated, with all values at 0.04 mg/l. While the benthic community in Naked Creek has occasional high populations of Chironomidae or Hydropsychidae – organisms associated with excessive nutrients, it has also contained high numbers of low pollution tolerant organisms. Nutrients were classified as a non-stressor.

### **3.2.5 Ammonia**

High values of ammonia are toxic to many fish species and may impact the benthic community as well. All ammonia values recorded at VADEQ ambient monitoring stations were at 0.04 mg/L, well below the chronic ammonia freshwater criteria of 1.79 mg/L. No fish kills have been reported in this watershed and nothing in the ambient monitored data indicates ammonia as a stressor, therefore ammonia was classified as a non-stressor.

### **3.2.6 Water Column Toxics**

Toxic substances by definition are not well tolerated by living organisms. The presence of toxics as a stressor in a watershed may be supported by very low numbers of any type of organisms, low organism diversity, exceedances of freshwater aquatic life criteria or consensus-based probable effect concentrations (PEC) for metals or inorganic compounds, by low percentages of the shredder population, reports of fish kills, or by the presence of available sources. Chronic toxicity testing was conducted on water column samples collected at station 1-BNAK001.24 in March 2007. The sample collected had a statistically significant effect on the fathead minnow survival and biomass. The test results showed no adverse affect on survivability of *Ceriodaphnia dubia*, also known as water fleas. However, the reproduction endpoint was statistically different from the laboratory control and also indicative of a biological effect at station 1-BNAK001.24. It should be noted that these toxicity tests do not provide information on the source of the toxics that may be affecting the fish community.

Feedback from the first TAC meeting prompted investigation into weed control along utility lines and rail road lines. Asplundh, Inc. was contacted with regards to herbicides being sprayed along the utility lines near Naked Creek. Frank Holloman, supervisor at Asplundh, Inc., advised the only spray being used along utility lines in the State of Virginia is “Garlon 4”, an herbicide. “Stalker” herbicide is also used on stumps along the utility lines, but was not currently being utilized. Jerry McClellan, supervisor at Asplundh Rail Division, advised that no herbicides were currently being sprayed along rail road lines Asplundh maintains. Herbicides typically used along rail road lines are “Oust” by Dupont and “Accord” by Dow Agro. No specific water quality measurements of these chemicals were available, but based on the limited use, limited toxicity, and limited extent of possible applications, it is very unlikely that these herbicides would be responsible for benthic impairment in Naked Creek.

Water column toxics were considered to be a non-stressor in Naked Creek based on the benthic taxa collected from the stream. Even in samples that were scored as “impaired”, very sensitive Plecoptera and Ephemeroptera taxa were present. Overall, 7 different families of Ephemeroptera and 10 different families of Plecoptera were observed in Naked Creek.

### **3.2.7 Sediment**

Sediment in Naked Creek was identified as a non-stressor. Out of 58 suspended sediment samples collected from Naked Creek since 1991, 55 were at the detection limit of 3 mg/L. The 3 samples above the detection limit were at 4 mg/L, 4 mg/L, and 16 mg/L. Habitat scores for embeddedness and sediment deposition were also good, and did not indicate that sedimentation was a stressor in Naked Creek.

## **3.3 Possible Stressors**

No stressors were classified as possible stressors in this study.



### 3.4 Most Probable Stressors

Chemical sampling of Naked Creek revealed excellent water quality and no pollutants that could reasonably be responsible for causing aquatic life impairment. The watershed remains 84% forested and contains limited pollutant sources. Most habitat conditions were also relatively good, with no indication of excess sedimentation, a typical problem in agricultural Shenandoah Valley streams.

The only marginal habitat scores were for channel alterations and lack of riparian vegetation. Additional investigation revealed that extensive channel alterations in the vicinity of station 1BNAK001.24 were the result of frequent flooding and stream restoration projects designed to restore and maintain the stream channel while protecting road and bridge infrastructure. Further investigation and analysis described below led to the determination that the most probable stressor in sections of Naked Creek (near station 1BNAK001.24) was habitat instability from naturally intense and frequent flooding.

#### 3.4.1 *Habitat Instability*

The headwaters of Naked Creek begin in the Blue Ridge Mountains. Several branches drain steep mountainous areas and flow through narrow hollows to form Naked Creek (Figure 3-1). Where these branches meet, Naked Creek transitions from very steep terrain and high gradient to a flatter floodplain. Approximately 80% of the Naked Creek watershed is characterized by steep forested ridges, with only 20% draining the flatter floodplain area. Within the mountainous 80%, slopes range as high as 124% or 51 degrees, and average 31% or 17 degrees. In comparison, the remaining 20% of land area exhibits an average slope of only 5.8% or 3 degrees.

The very mountainous terrain of the Naked Creek watershed, and the natural funneling of flow from these high gradient areas to the lower floodplain portion causes Naked Creek to be highly vulnerable to frequent and intense flooding. Large flood events, such as Hurricane Fran in 1996 and Hurricane Isabel in 2003 caused devastating effects including loss of property and infrastructure. Even more frequent, smaller events have continued to shape and reshape the Naked Creek channel. This has led to a pattern of ongoing channel instability and cycles of disturbance and recovery. This is particularly true of a 2-mile segment of Naked Creek from the confluence of the two forks to station 1BNAK001.24 (Figure 3-1). Habitat instability within this reach due to frequent flooding and channel migration is believed to be impacting benthic macroinvertebrate communities at the 1BNAK001.24 station.

The 2-mile section above station 1BNAK001.24 shows substantial evidence of ongoing channel instability. This includes effects from large flood events as well as gradual morphological changes during periods between events. Aerial imagery of the watershed was investigated to identify evidences of channel instability. Figure 3-2 shows some of the direct results following Hurricane Isabel. This flood occurred in September of 2003, and the aerial imagery displayed was collected in the spring of 2004, approximately 6 months after the catastrophic flood event. This image shows where bridges and roadways were washed out, replaced, and fortified with rip rap. The image also shows a section of stream that was re-

engineered with large cobbles and boulders that were deposited on the floodplain. Large areas of course and fine deposited materials are also evidenced by stream braiding that has occurred as the stream has recovered and cut new channels through the newly deposited material. The deposition of course material beneath bridges can also be observed from the imagery. All of these features are located within about 800 meters of the impaired benthic monitoring station, indicating significant disturbance at this site.

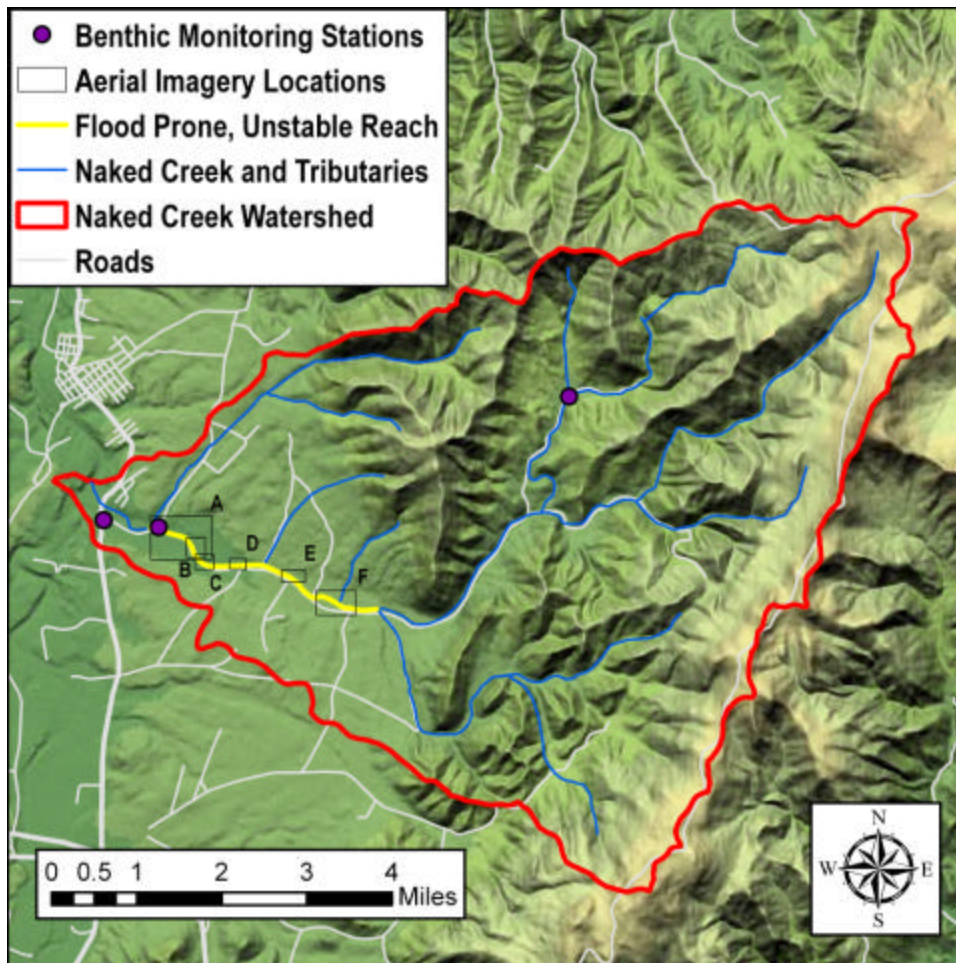
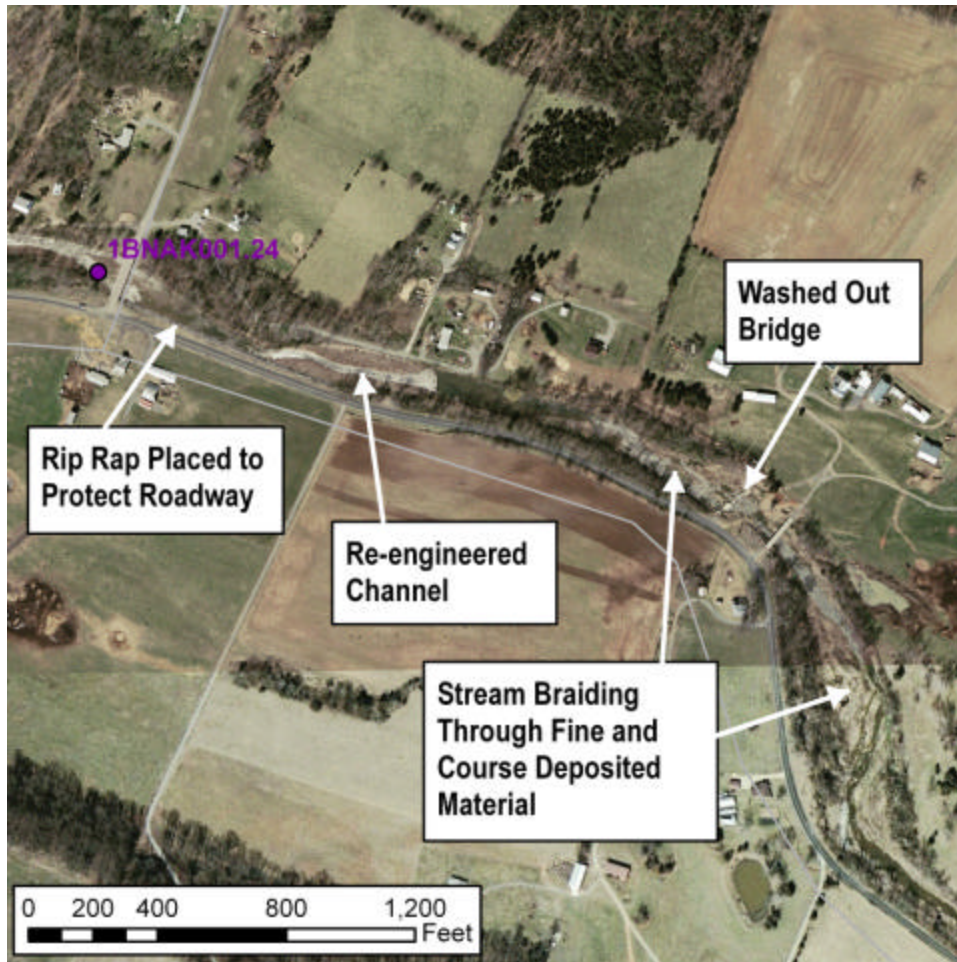


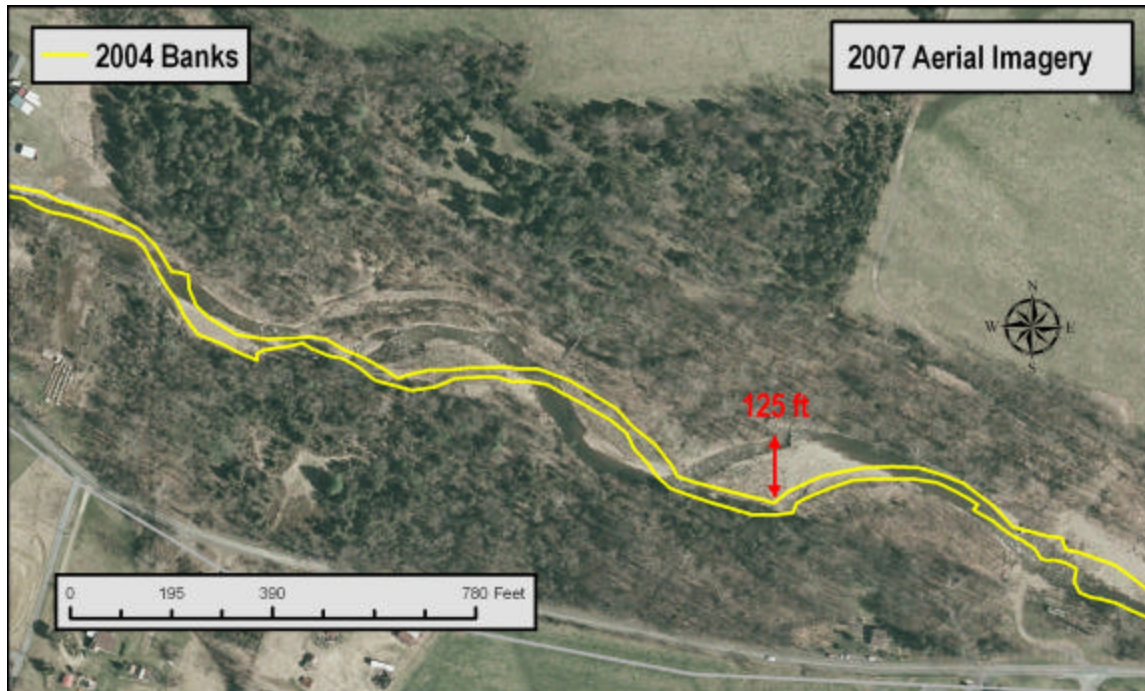
Figure 3-1. Topography of Naked Creek Watershed.



**Figure 3-2. Spring 2004 Aerial Imagery Showing Evidences of Disturbance and Channel Instability in Naked Creek Following Hurricane Isabel in 2003 (Aerial Imagery Location A).**

Evidences of stream disturbance and instability are not limited to the time period directly following large flood events such as Hurricane Isabel. Aerial imagery from spring 2004 (after Hurricane Isabel) was compared with aerial imagery from spring 2007 to evaluate ongoing changes to the Naked Creek channel. Within this 3-year period, aerial imagery shows significant instability and migration of the Naked Creek channel. Figure 3-3 and Figure 3-4 show two locations where the stream channel has moved significantly over a relatively short time period. At Location F, the meander bends have shifted phase and migrated a distance of over 125 ft. At Location B, just 800 meters upstream from benthic monitoring station 1BNAK001.24, the channel has migrated up to 167 ft over the 3-yr period. This location was the site of extensive stream restoration work following Hurricane Isabel. The restoration work re-established the channel further away from the road, however, 3 years later, the channel had migrated back to the edge of the roadway.





**Figure 3-3. Aerial Imagery (Location F) Showing Migration of the Naked Creek Channel from 2004 to 2007.**

Figure 3-5 shows another location (E) where the stream channel has migrated significantly since 2004. Ground-level observations at this location also revealed areas of active and severe bank erosion. At this location, approximately 300 ft of stream bank was actively eroding, and the height of the eroding bank was up to 15 to 20 feet high. This actively eroding bank showed evidence that channel migration was gradual and continual rather than just a result of periodic high flow events. In addition to lateral stream migration, this location also demonstrated the formation of bars or islands within the channel. This bar and island formation is another evidence of a high energy, unstable stream channel. Cobbles, gravels, and fine material are deposited under certain flow regimes to form these bars and islands. Over time, this deposited material may accumulate or be naturally reworked to create new channels. At this location, the newly formed bars represent nearly 1000 m<sup>2</sup> of material.

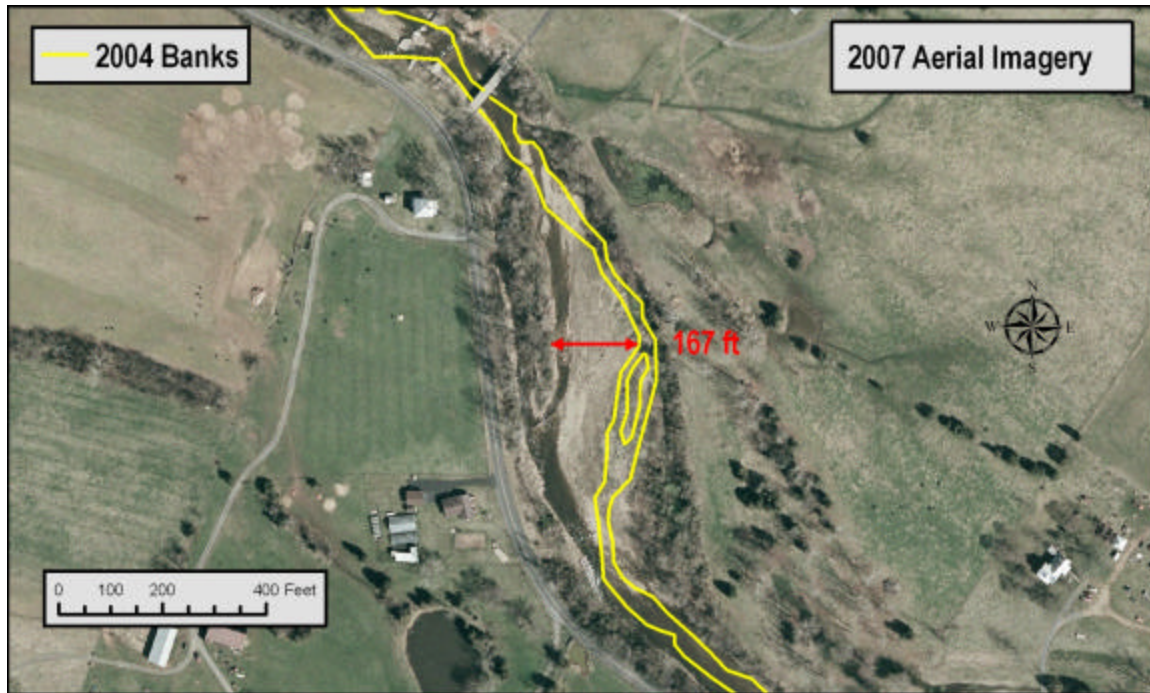


Figure 3-4. Aerial Imagery (Location B) Showing Migration of the Naked Creek Channel from 2004 to 2007.

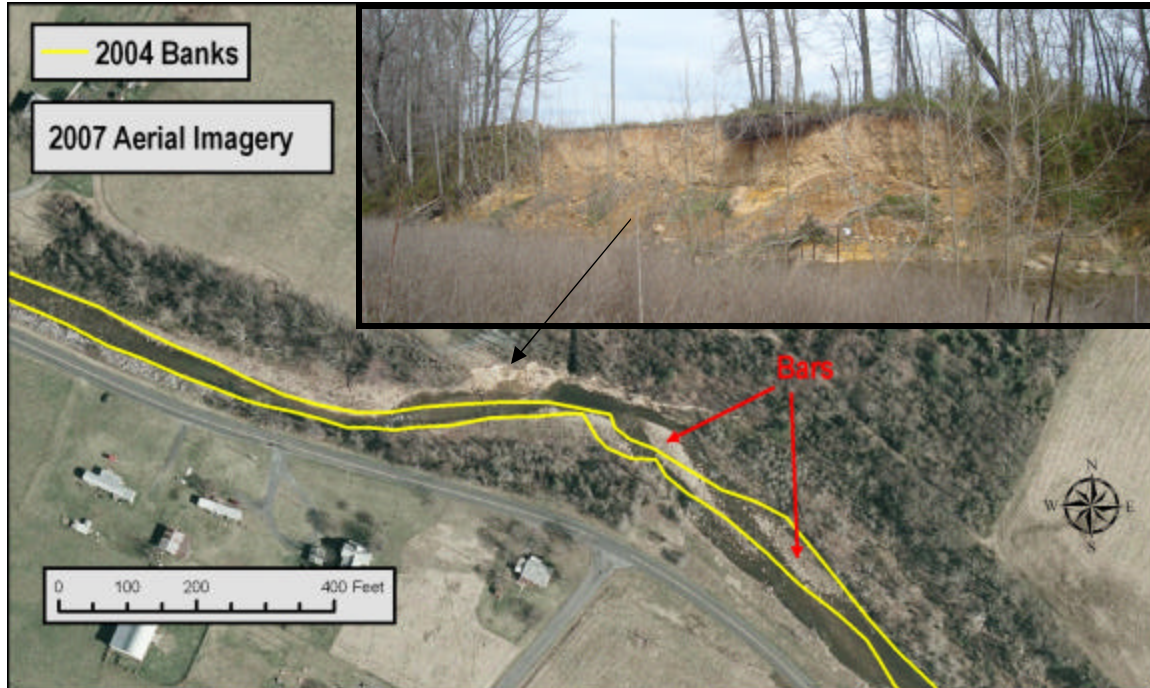
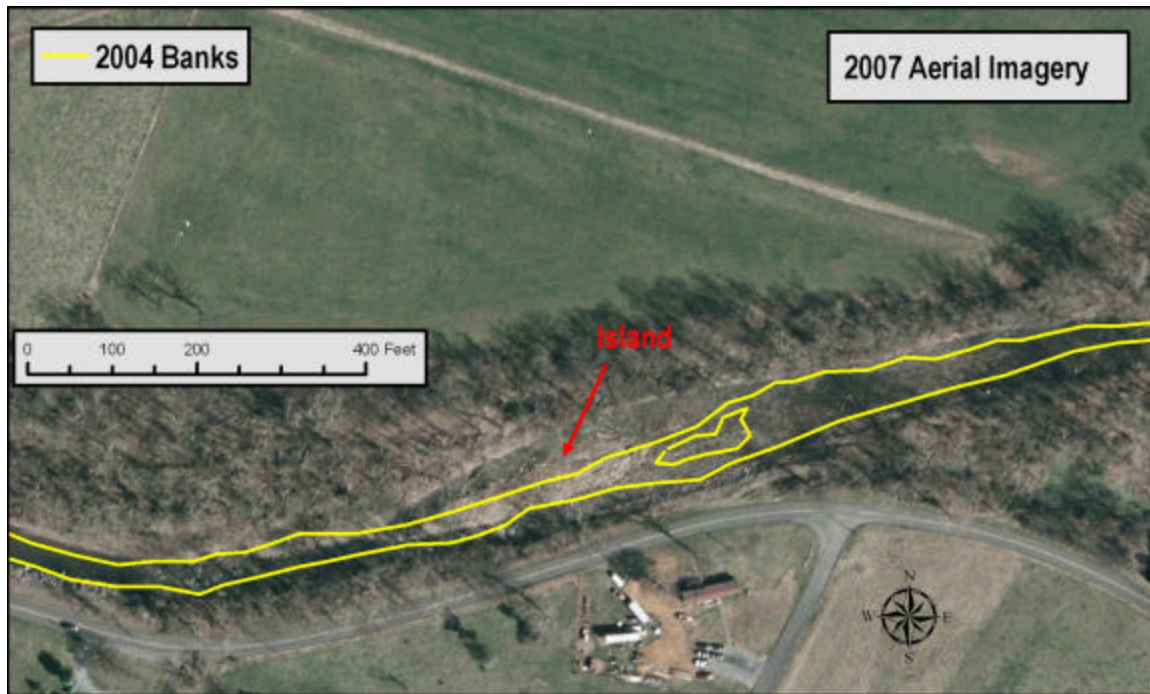


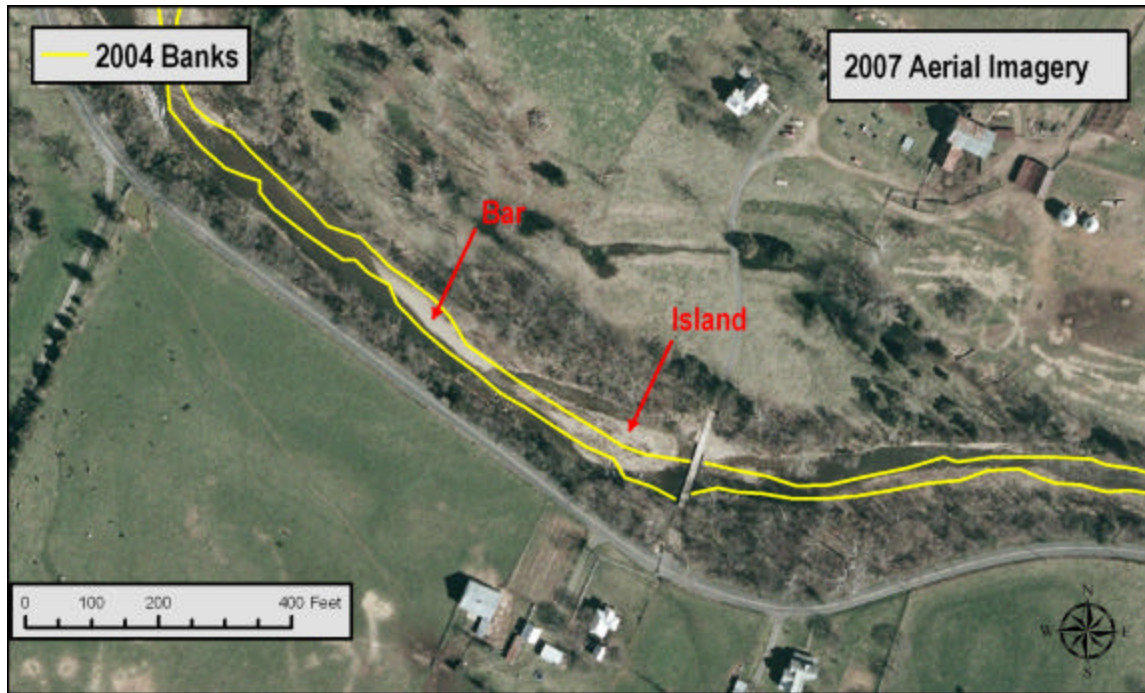
Figure 3-5. Aerial Imagery (Location E) and Ground-level Photography Showing Migration of the Naked Creek Channel and Formation of Bars from 2004 to 2007.



Figure 3-6 and Figure 3-7 show additional areas where large bars and islands have been formed over the past 3 years. At location D, a small island was present in 2004, but that island grew to over 1300 m<sup>2</sup> by 2007. At location C, islands and bars formed since 2004 represent over 2000 m<sup>2</sup>. Visual inspection of most of these areas revealed substrate that included large cobbles to boulders with embedded gravels and sands. The large diameter of deposited material in these areas demonstrates the high energy that Naked Creek flows produce on a regular basis.



**Figure 3-6. Aerial Imagery (Location D) Showing Migration of the Naked Creek Channel and Formation of Islands from 2004 to 2007.**



**Figure 3-7. Aerial Imagery (Location C) Showing Migration of the Naked Creek Channel and Formation of Bars and Islands from 2004 to 2007.**

In addition to the visual evidences of channel migration and instability in Naked Creek, records from the Virginia Department of Transportation (VDOT) and the Natural Resource Conservation Service (NRCS) document a large number of stream restoration or stabilization projects in the watershed. These projects were conducted to restore stream channels and protect property and infrastructure from flooding. Table 3-1 lists the number and extent of stream projects permitted within the Naked Creek watershed from 2004-2008. Overall, there were 37 VDOT projects and 6 NRCS projects that restored a total of 1.2 miles of stream channel and stabilized another mile of stream banks. Many of these projects, particularly NRCS projects conducted under the Emergency Watershed Protection (EWP) Program, also included the removal of course material deposited in the channel. These projects included over 12,000 cubic yards of material removed. The number and extent of these projects further demonstrates the flood-prone nature, instability, and frequent disturbance of Naked Creek.

**Table 3-1. Stream Restoration and Stabalization Projects in Naked Creek from 2004 - 2008.**

	VDOT	NRCS	Total
Number of Projects (since Isabel)	37	6	43
Length of Streambank/channel Restored (ft)	4,600	1,840	6,440
Length of Bank Stabilization (ft)	5,385	200	5,585
Volume of Material Removed (cy)	922	11,101	12,023



Multiple lines of evidence demonstrate that Naked Creek is naturally very flood-prone and that the high energy stream channel is very dynamic, migrating within the floodplain. These conditions create a natural pattern of disturbance and recovery. Superimposed upon this natural pattern are anthropogenic impacts from permitted stream restoration and stabilization projects that protect property and infrastructure. The instability, migration, and frequent disturbance of the stream channel results in a benthic community that may be impaired by scouring, sedimentation, or displacement. This is particularly true of benthic monitoring station 1BNAK001.24, which is just downstream of the most unstable reach of Naked Creek. All of the examples of channel migration and instability identified in Figure 3-3 through Figure 3-7 were located within two miles upstream of station 1BNAK001.24 (Figure 3-1).

To further investigate this conceptual model of benthic impairment resulting from habitat instability, an additional benthic monitoring station was added further downstream (1BNAK000.30). This station is approximately one mile downstream from the highly unstable reach and is within a segment that appears to be relatively stable. Figure 3-8 shows the location of the newly established station and the relative stability of the stream channel above this station. From 2004 to 2007 there is very little difference in the location of the stream channel within this reach.

In fall 2008, benthic monitoring data were collected from this new station as well as the two existing stations. Results showed that while the historically impaired station (1BNAK001.24) remained impaired, the newly established downstream station and the upstream station were unimpaired (Table 3-2). From an SCI score of 54.69 at the impaired station, scores improved to 65.58 within just a mile downstream. This score is well above the impairment threshold of 60 and represents a healthy benthic community. This finding further strengthens the conceptual model that observed impairment in Naked Creek results from habitat instability from a naturally dynamic and high energy system that is subject to intense and frequent flooding.

**Table 3-2. Stream Condition Index (SCI) Scores for Naked Creek Monitoring Stations in Fall 2008.**

Station	Fall 2008 SCI Scores
1BNAK000.30	65.58
1BNAK001.24	54.69
1BNKW001.97	69.03

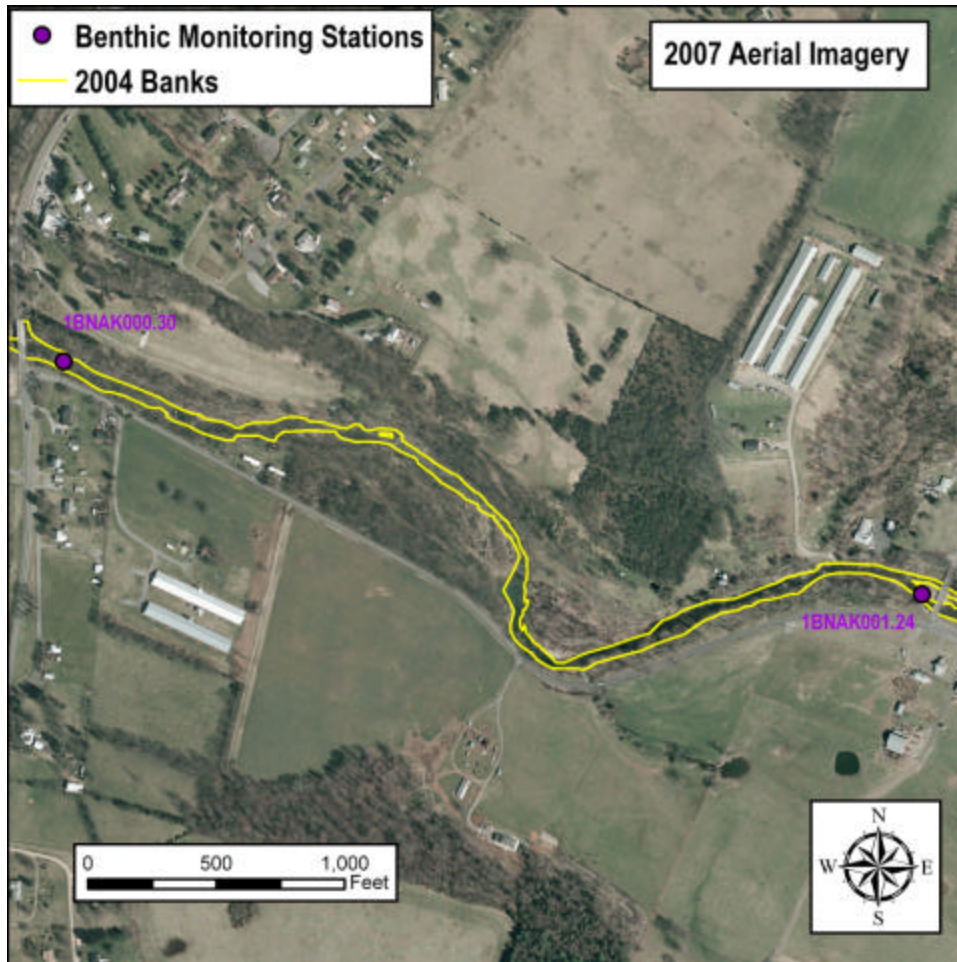


Figure 3-8. Location of New Established Benthic Monitoring Station.

## Chapter 4. Conclusions

The benthic stressor analysis for Naked Creek revealed no evidence that individual pollutants are responsible for causing the benthic impairment. Potential stressors such as pH, temperature, dissolved oxygen, biochemical and chemical oxygen demand, nutrients (nitrogen species and phosphorus), ammonia, sediment, and water column toxics, were all within natural ranges and were identified as non-stressors. No pollutants were identified as possible stressors.

The most probable stressor in Naked Creek was identified as habitat instability resulting from a naturally flood prone watershed. The natural topography of the Naked Creek watershed funnels high flows from steep mountainous areas onto a relatively flat flood plain. This has created an approximately 2-mile segment of Naked Creek at the base of the Blue Ridge Mountains that is very dynamic and highly unstable. Aerial imagery from 2004 to 2007 demonstrates significant migration and transformation of the stream channel within this 2-mile segment. Documentation from VDOT and NRCS also demonstrates this natural instability and flood potential. Numerous significant stream restoration and stabilization projects have been conducted in the watershed since 2003 to protect property and infrastructure from flooding and channel migration damage.

The impaired benthic monitoring station in Naked Creek is located at the end of this 2-mile highly unstable reach. To further demonstrate that the most probable stressor at this station is habitat instability, an additional benthic monitoring station was added about a mile downstream and within a much more stable reach. In fall 2008, this new monitoring station showed unimpaired conditions (SCI = 65.58), while the original station continued to show impaired conditions (SCI = 54.69).

Based on the stressor analysis determination that the most probable stressor is habitat instability resulting from a naturally flood prone watershed, VADEQ is petitioning USEPA to recategorize Naked Creek from "Category 5A – Impaired Needing a TMDL" to "Category 4C – Impaired Due to Natural Conditions".

## **Chapter 5. Public Participation**

The Naked Creek Benthic Stressor Analysis was developed with input from general public meetings and focused stakeholder meetings.

The first public meeting was held in the Town Hall in the Town of Shenandoah, VA on Tuesday, April 15, 2008. This meeting discussed the benthic impairment in Naked Creek and reviewed the approach for conducting the stressor analysis and developing a TMDL (if needed). Thirty-eight people attended the meeting. Copies of the presentation materials and various TMDL information handouts were available for public distribution. Public notice of the meeting was printed in the Virginia Register and advertised on the VADEQ and Central Shenandoah Planning District Commission websites. Notification regarding the meeting was sent to area appointed and elected officials and Local Steering Committee (LSC) members. Members of the LSC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meetings through advertisements in the community calendar section of local newspapers. There was a 30-day public comment period for the public meeting; however, no written comments were received.

The final public meeting will be held at the Shenandoah Community Center in Shenandoah, VA on May 18, 2009 to discuss the final stressor analysis and recommendation to change the impairment designation for Naked Creek. Copies of the draft stressor analysis report were available for public review and comment. Public notice of the meeting was printed in the Virginia Register and advertised on the VADEQ and Central Shenandoah Planning District Commission websites. Notification regarding the meeting was sent to area appointed and elected officials, LSC members, and prior public meeting attendees. Members of the LSC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meeting through advertisements in the community calendar section of local newspaper. There will be a 30-day public comment period for this meeting that extends from May 18, 2009 to June 18, 2009.

In addition to keeping the public apprised of progress in the development of the Naked Creek Benthic Stressor Analysis, a LSC was also established to help advise VADEQ. LSC meetings were held for this project on May 5, 2008 at the VADEQ Office in Harrisonburg, VA and November 20, 2008 at the Shenandoah Community Center in Shenandoah, VA. The LSC meetings were also advertised on the VADEQ and Central Shenandoah Planning District Commission websites. Notification regarding the meeting was sent to area appointed and elected officials and LSC members. The general public was solicited to participate on the LSC during the first public meeting in addition to agencies and groups already represented on the LSC. The LSC membership for this project included representatives from the following agencies and organizations:

- Virginia Department of Environmental Quality
- Virginia Department of Conservation and Recreation
- Virginia Cooperative Extension

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- Central Shenandoah Planning District Commission
- Shenandoah Valley Soil and Water Conservation District
- Page County

Eight and five people attended the April and November LSC meetings, respectively. LSC meetings were used as a forum to review data and assumptions used in the stressor analysis, and to provide local government agencies and stakeholders an opportunity to raise concerns about the implications of the TMDL for their jurisdictions. The generous assistance of the staff of these agencies is gratefully acknowledged.

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